NPE2024
The Plastics Show

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Produced by PLASTICS INDUSTRY ASSOCIATION

Designing for Circularity from Cradle to Grave

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Melissa holds an M.S. degree in Material Science and Engineering from Wayne State University. She has over 25 years of experience serving the global product development community across several industries including transportation, medical, and consumer products. She is an expert in material selection, test method development, and failure analysis.

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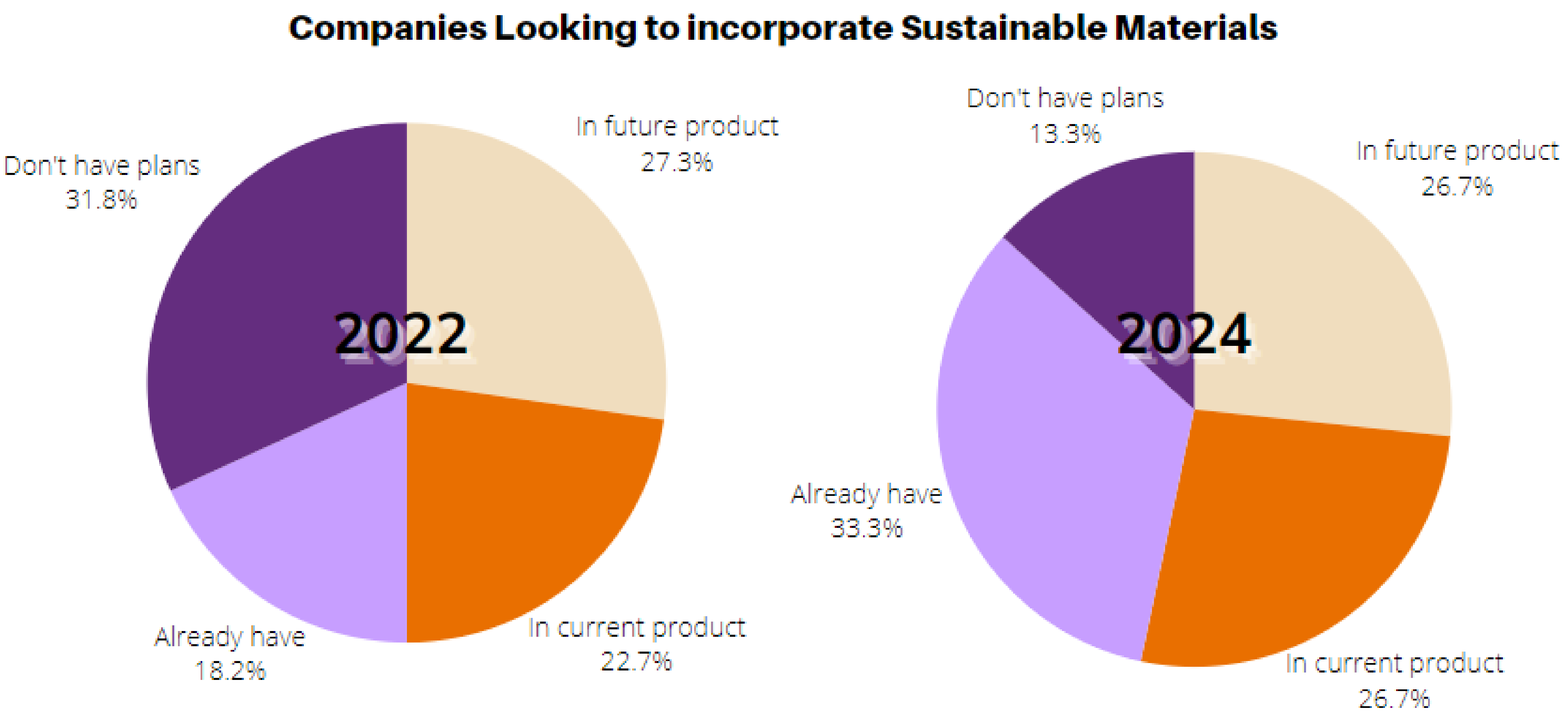
Introduction



Introduction (Continued)

Highest Priority Sustainable Materials

1. Those incorporating post consumer resin
2. Those originating from renewable resources
3. Those that are biodegradable

Biggest Obstacles to Sustainable Materials

1. Their performance is too variable
2. They are too expensive
3. Their supply is inconsistent

Objective

- Discuss the challenges associated with incorporating post-consumer resin into parts.
- Review potential solutions to address these challenges.
- Introduce ways to design products that will improve the facilitation of closing the material loop.

Recycled Resin

- When a material supplier states that their material incorporates recycled resin it could mean a few different things:
  1. It utilizes Post Consumer Resin (PCR)
  2. It uses Post Industrial Resin (PIR)
  3. It incorporates both PCR and PIR

Post Consumer Resin

- Post consumer resin (PCR) is essentially plastic waste associated with a consumer product that can no longer be used for its intended purpose.
  - Examples: Water bottles, food containers, shipping materials, car seats, toothbrushes, etc.

Post Industrial Resin

- Post industrial resin (PIR), is defined as plastic waste diverted during the manufacturing process. It has been converted into a product that is not saleable, and never making it to the consumer, aka “pre-consumer” waste.
  - If material is reused within the same process that generated it, for example sprue and runner systems ground and reintroduced back into the injection molding feed stream, it would be referred to as rework.
  - However, if those sprue and runner systems are introduced into a different molding process it would be considered PIR.

PCR vs. PIR

- PIR is often considered related to “production efficiency” rather than sustainability or circularity because it is recovered material waste or excess product from a company’s manufacturing processes.
  - Keep in mind some OEMs do not allow for the incorporation of regrind into their product and do not use hot runner systems.
- PCR is typically the focus when it comes to sustainability and circularity.
- Many resins incorporating recycled content have both.

How to Incorporate PCR

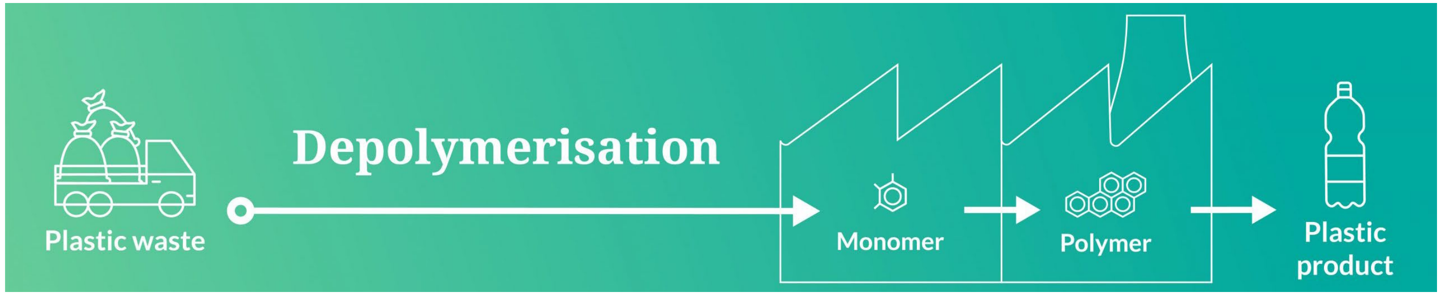
- There are two ways to incorporate PCR into materials:
  - Chemically recycled resins
  - Mechanically recycled resins

Chemically Recycled Resins

- Chemically recycled resins will be defined for the purpose of this presentation as resins compounded to incorporate chemically recycled post consumer resin (PCR).
    - This PCR can be chemically recycled by multiple methods including:
        - Purification
        - Depolymerization
        - Feedstock recycling
- The disadvantages of chemically recycled resins include
    - Higher cost
    - Limited chemistries
    - Green benefits

Chemical Recycling - Depolymerization

- This category is the opposite of polymerization. It describes chemical methods that yields either single-monomer molecules or shorter polymer fragments known as oligomers.
- These monomers are identical to those used in the preparation of polymers and because of this, the plastics prepared from depolymerization are similar in quality to virgin monomers.
- Target feedstock are limited to condensation polymers, such as polyesters (PET), polyamides (PA), and polyurethanes.
- It cannot be used for addition polymers, such as PP, PE, and PVC.



Investments in Depolymerization

- Eastman has invested a considerable level of resources in its polyester renewal technology via methanolysis depolymerization to chemically recycle PET waste.
  - Building plants in Tennessee and France with the commitment of recycling more than 250 million pounds of plastic waste annually by 2025 and more than 500 million pounds of plastic waste annually by 2030.
- Sabic also has the capability to use chemical processes to depolymerize PET bottles and other waste into their precursor chemicals, purify them and then use them to create new resins.

Eastman's Kingsport depolymerization plant.

Investments in Depolymerization (Continued)

- Trinseo is investing in a polymethyl methacrylate (PMMA) depolymerization plant in Italy. Scheduled to be commissioned in Q1 2024.
- This depolymerization operation will be designed to enable the efficient recycling of end-of-life PMMA, which will ultimately be used to produce acrylic resins, sheets, and compounds containing recycled materials.

Trinseo Manufacturing Operations, Rho, Italy. Site of future demonstration PMMA depolymerization facility.

Chemical Recycling – Feedstock Recycling

- This category describes any thermal process that converts polymers into simpler molecules, to form the feedstock for petrochemical-type processing.
- The outputs of feedstock recycling are basic chemicals (e.g., hydrocarbons or synthetic gas), which need to be processed further to yield a polymer. This allows flexibility for reuse in the petrochemical industry.

Chemical Recycling – Pyrolysis

- Pyrolysis is one type of feedstock recycling. It breaks plastics down into a range of basic hydrocarbons by heating in the absence of oxygen.
- Pyrolysis products can be processed in much the same way as oil, using conventional refining technologies to produce building blocks for polymers. They can also be used directly as a fuel.
- Target feedstocks include PE, PP, polybutylene (PB), polystyrene (PS), and poly(methylmethacrylate) (PMMA).

Investments in Pyrolysis

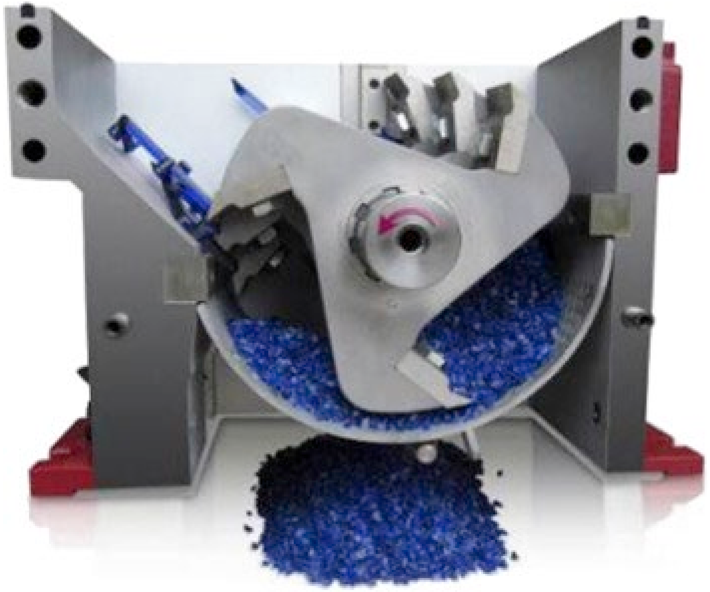
- Sabic's Trucircle portfolio include polyethylene and polypropylene polymers that are produced with a feedstock of pyrolysis oil. The pyrolysis oil is produced from recycled mixed used plastics using chemical recycling technology. It is important to note that the recyclate would be either PCR or PIR in nature.

Chemically Recycled Resins – Material Options

Resin	Manufacturer	Tradename	Applications
Copolyester	Eastman	Cristal™ Renew	Packaging, consumer goods, lighting, and electronics
	Eastman	Tritan™ Renew	
Polypropylene	Sabic	PP T2E-19T1040 PP T2E-3320EH PP T5E-15T1020 STAMAX™ T2E-40YR240 STAMAX™ T2E-30YR240 STAMAX™ T5E-40YR270E	Automotive
PBT	Sabic	LNP™ ELCRIN™	Consumer goods, automotive, and electronics
PC/PBT	Sabic	LNP™ ELCRIN™	Consumer goods, automotive, and electronics
PMMA	Trinseo	ALTUGLAS™ R-Life	Automotive, building, consumer goods, lighting

Mechanically Recycled Resins

- Mechanically recycled resins will be defined for the purpose of this presentation as resins compounded to incorporate mechanically recycled post consumer resin (PCR).
  - Mechanical recycling is the process of recovering plastic waste by mechanical processes such as sorting, washing, drying, and grinding. Re-granulating and compounding can also be performed.
- The challenges with using these types of materials are:
  - Higher costs
  - Inferior mechanical performance
  - Processing variability
  - Inconsistent quality



Mechanically Recycled Resins – Performance

- It is likely that mechanically recycled resins will exhibit different properties relative to a 100% virgin resin.

Material Type	MVR (cm^3/10 min.)	Tensile Modulus * (MPa)	Tensile Yield Strength* (MPa)	Tensile Yield Strain * (%)	Charpy Notched Impact Strength* (kJ/mm^2)
ABS Virgin	**19**	**2300**	**45.0**	**2.6**	**22**
ABS Virgin with 50% PCR	19	2100	35.0	2.6	18
ABS Virgin with 70% PCR	17	2100	36.0	3.6	17

** Nominal properties at room temperature data obtained using ISO test methods.*

Mechanically Recycled Resins – Performance

- These resins will also have more variability in their mechanical performance from lot to lot.
- This is because there is more variability in the performance of the source material, due to the potential variation in the commercially available grades of material.

Material Type	Commercially Available Injection Molded Grades	Tensile Strength* (MPa)	Charpy Notched Impact Strength* (kJ/mm^2)
Polycarbonate (Unfilled)	>2,600	73 – 45	No Break – 2.5 (@ -30 °C)
ABS (Unfilled)	>1,600	47 – 35	60 – 6
PC/ABS (Unfilled)	>750	65 – 40	50 – 10 (@ -30 °C)

** Nominal properties at room temperature data obtained using ISO test methods, unless noted.*

Mechanically Recycled Resins – Processing Variability

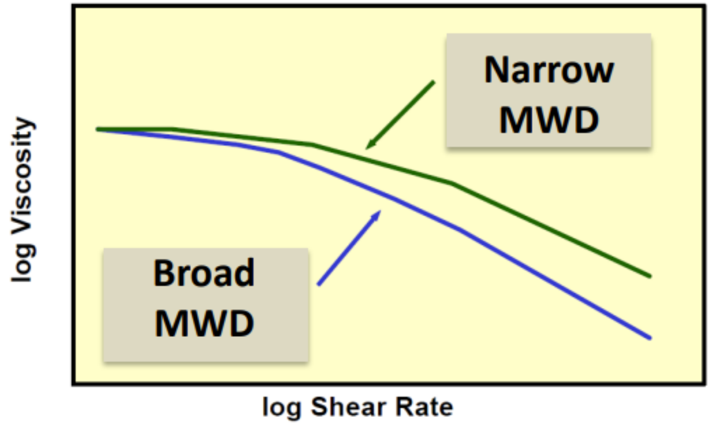
- The processing variability in mechanically recycled resins stem directly from the PCR content.
- The processability can be influenced by several variables including:
  - Molecular weight/molecular weight distribution
  - Contamination
  - Pellet size and shape

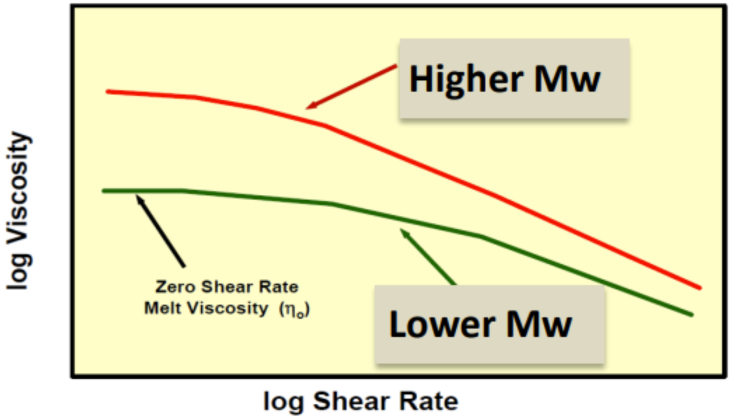
Processing Variability – Molecular Weight

- The molecular weight of a polymer type can vary greatly by their grade.

Material Type	Commercially Available Injection Molded Grades	Melt Flow Rate (g/10 min.)
Polycarbonate (Unfilled)	>2,600	180 – 2.0
ABS (Unfilled)	>1,600	230 – 2.0
PC/ABS (Unfilled)	>750	90 – 11

- The material's resistance to flow during processing (i.e., viscosity) will be determined by its molecular weight (and shear rate).

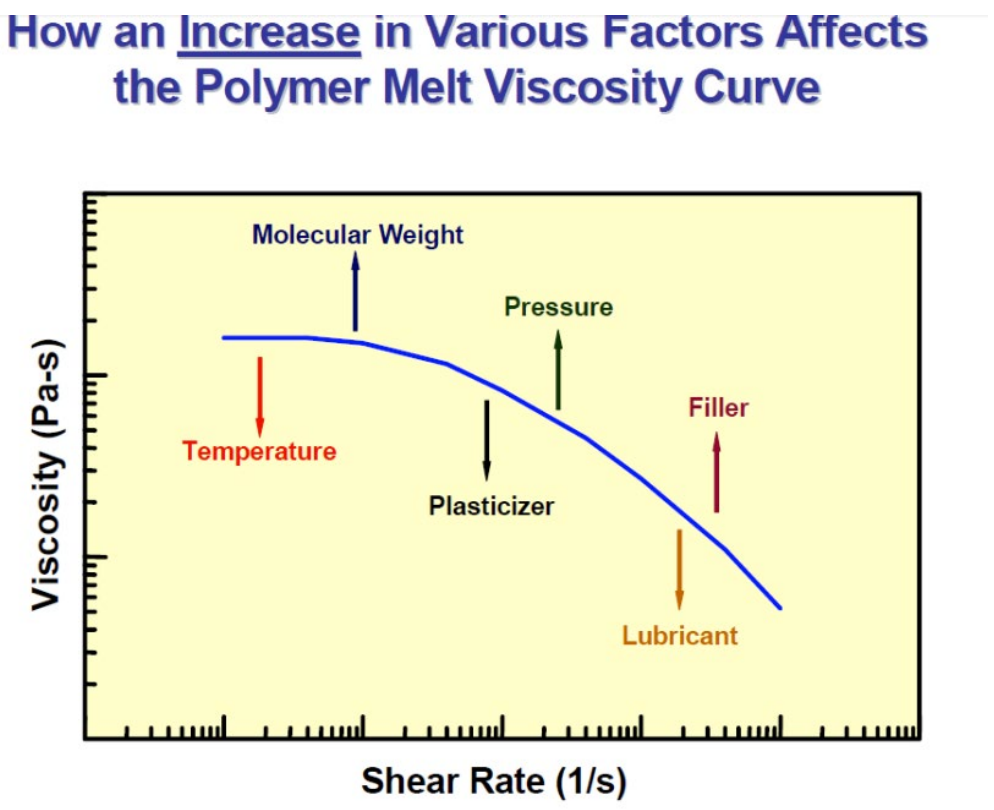




Source: Dynisco

Processing Variability – Contamination

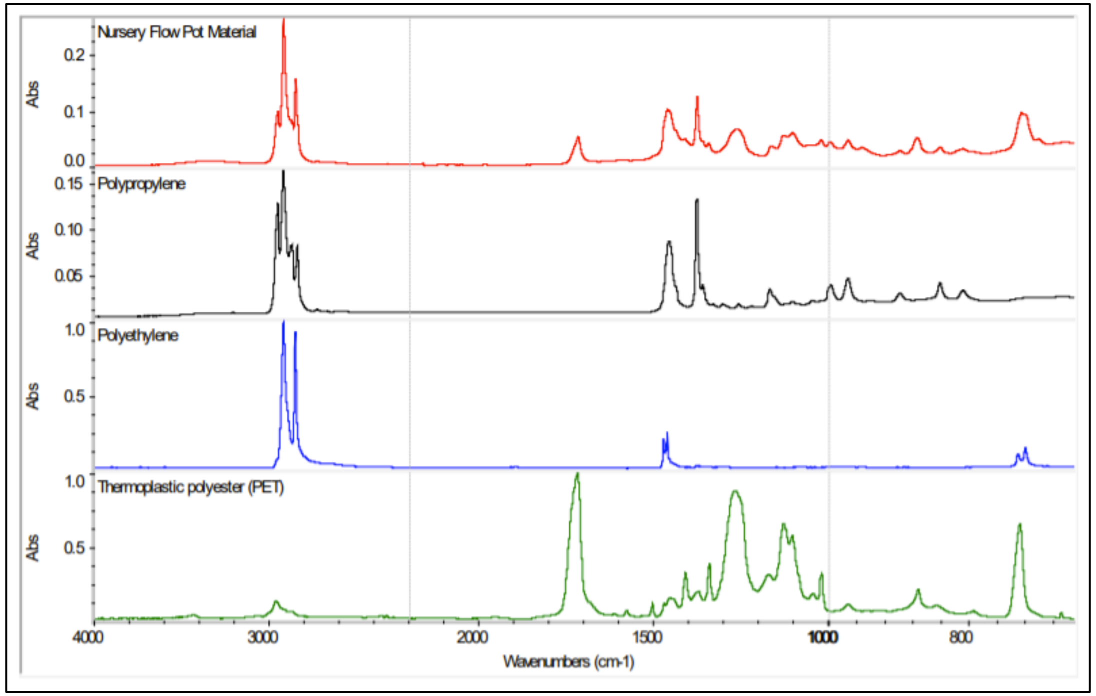
- PCR can incorporate contaminants in the form of compounding ingredients (i.e. plasticizer, processing aids, fillers, stabilizers, flame retardants, etc…)



Source: Dynisco

Processing Variability – Contamination

- PCR could also contain (unintentional) contamination from the original product material.
  - If the PCR incorporates contaminants that do not melt at the same temperature as the base resin this could lead to high processing variability

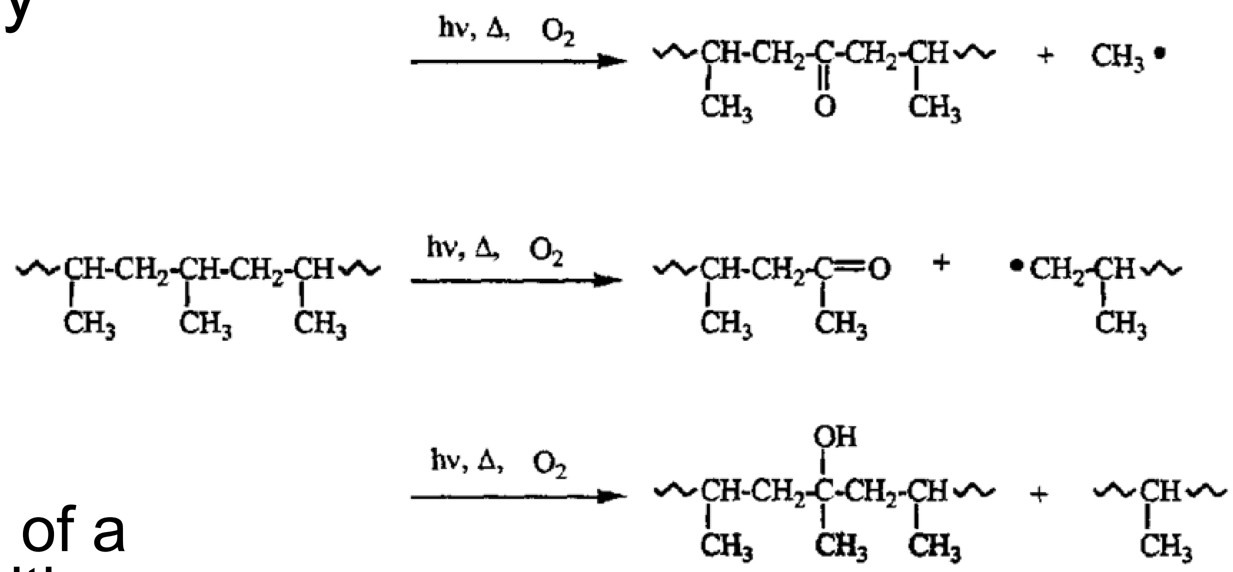


Processing Variability – Pellet Size and Shape

- Pellet size and shape
  - Differences in size and/or shape of pellets can lead to irregularities in the polymer melts during processing.

Mechanically Recycled Resins – Inconsistent Quality

- One possible contributing factor to the inconsistent quality of mechanically recycled resins is their thermal stability.
- All polymers are susceptible to thermal oxidation both during processing and during use in the application.
    - Thermal oxidation is the degradation of a polymeric material through contact with a chemical oxidizer. It is a chemical reaction where oxygen is introduced into the molecular structure of the polymer.



Thermal Oxidation Reactions of Polypropylene

Inconsistent Quality – Thermal Stability

- The effects of thermal oxidation include:
  - Reductions in molecular weight
    - Embrittlement
    - Diminished mechanical performance (i.e. strength, ductility, toughness)
    - Formation of cracks
  - Changes in appearance
    - Discoloration
    - Loss of gloss
    - Loss of transparency
  - Evolution of volatiles
    - Odor generation

Overcoming These Challenges

- Mechanical Performance
  - Determine the range of mechanical properties that you will receive lot to lot.
    - Request property data over nine unique lots manufactured within a 12-month timeframe.
  - Ensure that you have or can build enough safety factor into your design.
    - FEA, product testing.
  - Determine your key property requirements and request that the lots be certified to these requirements.

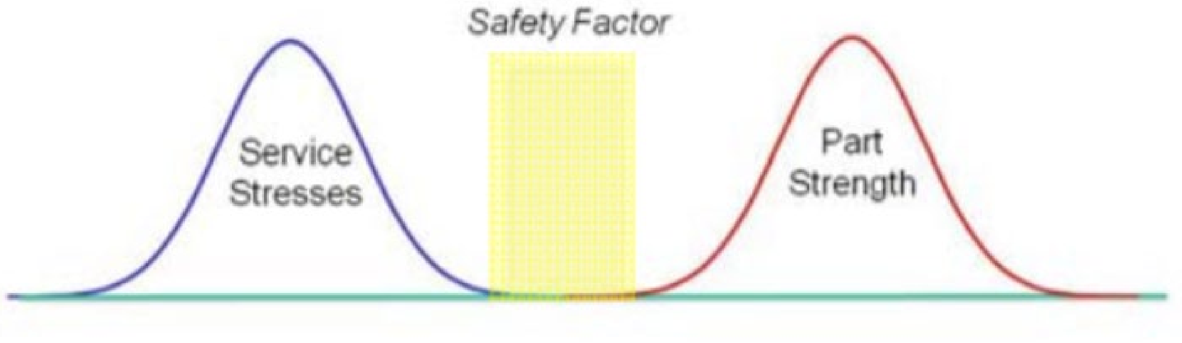


Figure 1. Distributions of part strength and service stresses separated by a design safety factor.

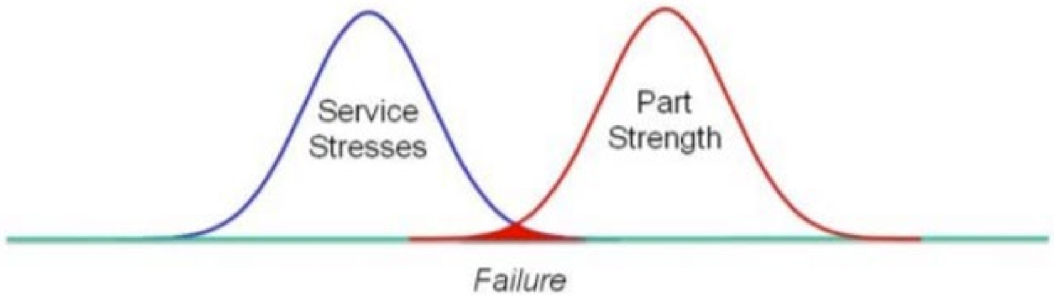


Figure 2. Distributions of part strength and service stresses overlapping leading to failure.

Overcoming These Challenges (Continued)

- Processing Variability
  - Characterize the viscosity versus shear rate of the material over several lots will help determine the behavior to expect during the injection molding process.
    - If the variability is significant characterize the material's viscosity versus shear rate for each incoming lot.
  - To eliminate the effect of the size and shape of PCR on the polymer melt it should be compounded (blended and repelletized) with the base resin.
  - The material supplier should have a robust process for controlling the composition, minimizing contamination, of the PCR.
    - Even with the most robust incoming quality control it is possible that contamination can exist.
    - Evaluate multiple lots of mechanically recycled resins to determine if your process/part can tolerate the degree of contamination present.

Overcoming These Challenges (Continued)

- Inconsistent Quality
  - PCR is even more susceptible to thermal oxidation because it has already experienced at least one, if not more, heat histories. The material needs to be protected through at least its third heat history to prevent thermal oxidation as well as molecular degradation.
  - Material suppliers should be incorporating antioxidants and testing for their consumption during the compounding process to ensure that there is sufficient stabilization available for the molding process.

Mechanically Recycled – Material Options

Resin	Manufacturer	Tradename	Applications
PC	Trinseo	Emerge™	Automotive, appliances, electronics and consumer goods
	Sabic	LNP™ ELCRIN™	
	LG Chem	LetZero Lupoy®	
PC/ABS	Trinseo	Emerge™	Medical, electronics, and consumer goods
	LG Chem	LetZero Lupoy®	
ABS	Trinseo	Emerge™	Electronics and medical
	INEOS Styrolution	Terluran® ECO	
	LG Chem	LG ABS MRC	
PBT	Celanese	ECO-R	Automotive
PBT + PET	LyondellBassel	Schuladur® PCR	Automotive and electronics
PC + PET	Sabic	Xenoy™ T2RX	Automotive, appliances, and electronics

Mechanically Recycled – Material Options

Resin	Manufacturer	Tradename	Applications
PP	Washington Penn Plastics		Automotive, household goods and appliances
	RheTech		
	LyondellBasell Industries		
	Braskem		
	Wellman Advanced Materials	Ecolene™	
	Braskem		

Mechanically Recycled – Material Options

Resin	Manufacturer	Tradename	Applications
Nylons	Wellman Advances Materials	Ecolon®	Automotive, consumer goods and electronics
	DuPont	Durethan® ECO	
	Teknor Apex	Recyclon®	
	DSM Engineering Materials	Akulon® RePurposed	
TPE	Avient Corporation	reSound®	Sealing, automotive, consumer goods
	Celenese	Santoprene® ECO	
	HEXPOL TPE	Dryflex®	
	KRAIBURG TPE	Thermolast®	
	Teknor Apex	Monoprene®	

Nimble CHAMP Portable Chargers

- 72.5% to 90% post consumer plastic
  - Polycarbonate
  - PET
  - Silicone

Yakima RocketBox Pro 14 Roof Box

- Up to 80% recycled plastic
  - ABS

Leyform Greta Chair

- 100% recycled plastic
  - Polypropylene

Black+Decker® reviva™ Tools

- Up to 50% recycled plastic
  - Copolyester

Electrolux 500-900 Series Refrigerators

- Liners 70% recycled plastic
  - ABS or HIPS

End of Life

- Waste
  - Landfill
  - Incineration
- Municipal recycling
  - Polypropylene
  - Polyethylene
  - PET
- Consumer take back programs
  - Recycling partners

Source: Wood Mackenzie

Designing for End of Life

- Ease of Disassembly
  - Fasteners or snap-fit
  - Welding of same materials only
  - No adhesives
  - No overmolding
- Clearly label materials
  - Mark different materials to aid sorting and recycling

Designing for End of Life (Continued)

- Decoration
  - Laser marking/engraving
  - Embossing/debossing
  - Molded in color
  - No painting or plating

Thank you!

THE MADISON GROUP
PLASTIC CONSULTING ENGINEERS

The Madison Group is the recognized leader in plastics engineering. Over the course of three decades The Madison Group has focused on polymeric materials. We understand how these materials behave, how to properly design with them, how they are processed, and the numerous manufacturing steps required to produce a successful product. Our capabilities include:

- Design Review
- Material Support
- Product Testing
- Manufacturing Support
- Failure Analysis
- Customized Training

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